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Mass-to-Surface Area Index in a Large Cohort

LAWRENCE E. ARMSTRONG, JANE P. DE LUCA, ELAINE L. CHRISTENSEN, AND ROGER W. HUBBARD
Heat Research Division, U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760-5007

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ABSTRACT Many biological and anthropological investigations have described the role between mass-to-surface area index (M/SA) and heat tolerance. No large M/SA database exists that can be used as a reference standard to interpret previous or future M/SA studies. This report presents the M/SA data of a large military cohort (1,170 males aged 17–54 years, 305 females aged 17–40 years). The effects of gender, ethnic group, and age on the distribution of M/SA, as well as the relationship between M/SA and other physical characteristics, were described. It was observed that the increases of M/SA with increasing age (over the 17–75 years category) were not significant. All descriptive characteristics (including M/SA) were different ($P < .001$) between males and females. M/SA was not statistically different between ethnic groups among both males and females. These data may be utilized to compare the M/SA values of U.S. citizens to those of other ethnic groups and to identify those laborers or athletes who possess the greatest theoretical risk of heat intolerance.

Winslow and Gagge (1941) first reported that a large man dissipated more heat than a small man in a warm-humid environment (21°C, 40–50% RH) because body size played an important role in determining the magnitude of radiant heat dissipation. One year later, Robinson (1942) expressed body morphology in terms of body mass per square meter of skin surface area (M/SA), realizing that the heat exchange process was multifaceted. Two male subjects ran or walked up a grade on a motor-driven treadmill in a hot-wet environment of 32°C, 70% rh. The exercise efficiencies of these two men were the same, but the M/SA index of the large man (44 kg · m^{-2}) was 20% greater than that of the small man (35 kg · m^{-2}), and heat storage was strongly influenced by their M/SA values. These two studies spawned many subsequent anthropological (Austin and Ghesquiere, 1976; Benoist, 1975; Hiernaux et al., 1975; Newman and Munro, 1955; Schreider, 1950; Wyndham, 1970) and biological (Austin and Lansing, 1986; Bar-Or et al., 1969; Epstein et al., 1983; Fein et al., 1975; Paolone et al., 1978; Piwonka et al., 1963; Shapiro et al., 1980; Shvartz et al., 1973; Wagner et al., 1972; Wailgum and Paolone, 1984) investigations, which described the role between M/SA and heat storage/dissipation. These investigations were especially relevant because hyperthermia 1) is a primary indicator of heat intolerance, 2) results in reduced physical and mental performance independent of body hydration status, and 3) is the major danger to health during heat stroke. In addition, several researchers suggested that the calculation of M/SA provided a theoretical means to identify individuals who were susceptible to heat injury (Austin and Ghesquiere, 1976; Epstein et al., 1983; Robinson, 1942; Shapiro et al., 1980; Wagner et al., 1972; Wailgum and Paolone, 1984).

The anthropological relationship between human morphological variation and climate was first introduced by Schreider (1950). His data, which suggested ethnic group and gender effects of M/SA, resulted in noteworthy

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research in recent years. These studies attempted to support or challenge the hypothesis that M/SA decreases as the mean annual temperature of the environment increases. A variety of ethnic groups were evaluated, including inhabitants of the United States (Newman, and Munro, 1955), West-Central Africa (Hiernaux et al., 1975), Zaire (Austin and Ghesquiere, 1976), Israel, Europe, North-Central Africa, and Asia (Benoist, 1975). Although some of these studies supported Schreider's hypothesis, a series of laboratory studies by Wyndham (1970) found ethnic factors to be unimportant.

Clearly, further research must be conducted to clarify the relationships between M/SA, biological, and anthropological factors. Unfortunately, it is difficult to compare and interpret previous studies because they have involved small samples. No large database exists that can be used as a reference standard for M/SA studies. Therefore, the purpose of the current investigation was to provide a large database that can be used to interpret the M/SA values of healthy subjects, aged 17–54 years (males) and 17–40 years (females). This report presents data on a total of 1,475 (1,170 males, 305 females) active duty personnel from a variety of units and assignments in the U.S. Army. The U.S. Army is a suitable population for a comprehensive assessment of M/SA because of its broad representation of the national population as well as its accessibility. Because this investigation utilized a large heterogeneous sample, an analysis of the influences of gender, age, and ethnic group on M/SA is included as well as the first normative description of those individuals who have the greatest theoretical risk of hyperthermia and heat illness.

MATERIALS AND METHODS

Anthropomorphic and physical fitness data were obtained from a sample of 1,475 U.S. Army officers and noncomissioned officers at Fort Hood, Texas, and Carlisle Barracks, Pennsylvania. Subject medical records were reviewed, and a physical examination was administered prior to participation in most cases. Those who were free of significant disease or debilitating orthopedic injuries were utilized for this investigation. Informed voluntary consent was obtained from all subjects. Observations were conducted in accordance with the human experimentation policy statement of the American College of Sports Medicine and the local Human Use Review Committee.

The following values were incorporated into this data base: gender, ethnic group, height (H), body mass (M), percent body fat (%BF), fat-free mass (FFM), maximal aerobic power, and 2-mile run time recorded as a part of the Army Physical Readiness Test. Standard statistical analyses were performed by computer, using commercial statistical software (BMDP, Los Angeles, CA). The ethnic categories were based on those suggested by Wallman and Hogdon (1977). Due to relatively small sample sizes, ethnic groups other than white or black were combined in the category called "other". Age categories were chosen that would be both physiologically meaningful and that would encompass an adequate sample size. Any gender, age, or ethnic category with less than 29 subjects was eliminated from the data in Table 2 and Figures 1 and 2.

Aerobic power was measured as maximal oxygen uptake (VO_2 max) using a continuous incremental treadmill test adjusted for sex, age, and activity level. Subjects aged 17–34 years, and physically active subjects aged 35–39 years, ran to exhaustion as the treadmill grade increased 2.5% every 3 min (maximum of 15%); treadmill speed was increased by 0.2 $m \cdot s^{-1}$ every 3 min from the initial speeds of 2.6 $m \cdot s^{-1}$ (males) and 2.2 $m \cdot s^{-1}$ (females). Inactive subjects aged 35–39 years, and all subjects aged 40–54 years, underwent trials which began at 1.5 $m \cdot s^{-1}$ and 0% grade; the treadmill grade increased 2.5% every 3 min to a maximum of 15%. If necessary, the test was then continued at 2.6 $m \cdot s^{-1}$ and 0% grade, and the grade increased 2.5% every 3 min.

During body composition measurements, all subjects were measured by the same investigators, using the same techniques. Body mass and height were measured on a platform balance (Sauter Inc., nearest 0.1 kg) and by standing against a premeasured wall ruler (nearest 0.1 cm), respectively. Body density and %BF were estimated using a hydrostatic weighing procedure similar to that of Goldman and Buskirk (1961), as described by Fitzgerald et al. (1986). A desktop computer (Hewlett-Packard, model 85) sampled underwater weight every 10–15 s, calculating body density according to the formula of Buskirk (1961) and %BF according to the formula of Siri (1961). SA was calculated by using height and body mass values

TABLE 1. Descriptive characteristics of all male and female subjects[1]

Characteristic	Males			Females		
	n	Mean	SD	n	Mean	SD
Age (years)	1,170	30.2	8.8	305	24.0	5.0
H (cm)	1,165	175.1	6.9	303	162.4	6.4
M (kg)	1,165	76.8	11.3	303	59.9	8.0
SA (m^2)	1,165	1.9	0.2	303	1.6	0.1
M/SA ($kg \cdot m^{-2}$)	1,165	39.8	2.9	303	36.5	2.4
%BF (%)	1,153	20.3	6.7	289	27.3	5.6
FFM (kg)	1,153	60.8	7.4	289	43.3	5.0
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	780	47.644	6.170	265	39.257	4.469
VO_2max ($liters \cdot min^{-1}$)	780	3.566	0.494	265	2.331	0.322
Two-mile run (min)	1,046	14.58	2.04	289	17.48	2.22

[1]All characteristics were significantly different (males vs.females) at the $P < .001$ confidence level.

according to the formula of DuBois and DuBois (1916). Both FFM and M/SA were calculated and incorporated into the data file. To compare M/SA among subsamples, subjects were categorized by sex, age, and ethnic group, and the 95% confidence limits (mean ± 2 SD) were calculated. Descriptive characteristics for all males and all females were expressed separately, and in the following three M/SA subsamples: small (subjects with M/SA smaller than −2 SD of the mean), large (subjects with M/SA larger than +2 SD of the mean), and average (subjects with M/SA within ±2 SD of the mean).

RESULTS

Table 1 presents the descriptive characteristics of the males and females who participated in this study (all ages, all ethnic groups). Portions of these results have been published elsewhere (Fitzgerald et al., 1986; Vogel et al., 1986). Statistically significant ($P < .001$) differences between males and females existed in all characteristics presented in Table 1. The 95% confidence limits for male M/SA were 34.0–45.6 $kg \cdot m^{-2}$ and were 31.7–41.3 $kg \cdot m^{-2}$ for female M/SA.

Figures 1 and 2 show the M/SA distribution for all males and all females, respectively. The means (±SD) M/SA for all males and females were 39.8 ± 2.9 and 36.5 ± 2.4 $kg \cdot m^{-2}$, respectively.

Table 2 presents the mean (±SD) M/SA of males and females categorized by age and ethnic group. The increases of M/SA with increasing age (over the 17–25 year age category) were not significant. M/SA was statistically similar between ethnic groups, at all ages, in both males and females. However, black males (all ages) had a lower %BF

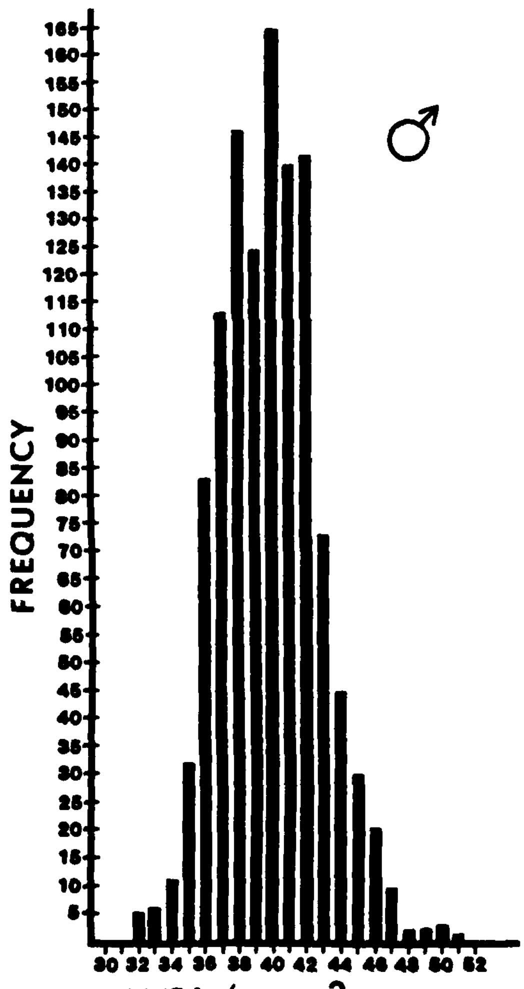

Fig. 1. Frequency distribution of M/SA for all males (n = 1165). The mean (±SD) M/SA value was 39.8 ± 2.9 $kg \cdot m^{-2}$.

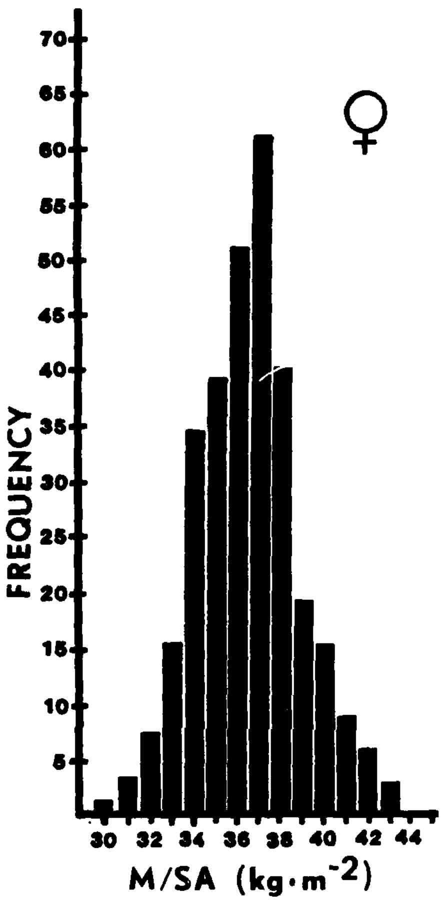

Fig. 2. Frequency distribution of M/SA for all females (n = 303). The mean (±SD) M/SA value was 36.5 ± 2.4 kg · m^{-2}.

TABLE 2. M/SA (kg · m^{-2}) categorized by gender, ethnic group, and age

Ethnic group	Age group (years)	n	M/SA Mean	M/SA SD
Males				
Black	17-25	116	38.9	2.5
Black	26-34	108	39.9	3.2
Black	35-39	31	40.9	3.2
White	17-25	255	38.9	2.6
White	26-34	149	40.4	3.0
White	35-39	76	41.0	3.3
White	40-49	227	40.6	2.2
Other[1]	17-25	57	38.3	3.0
Other[1]	26-34	71	39.9	3.0
Other[1]	35-39	31	40.6	3.5
Females				
Black	17-25	83	36.2	2.1
Black	26-34	29	37.4	2.1
White	17-25	106	36.0	2.2
White	26-34	42	37.4	3.1

[1]"Other" includes the following groups: Hispanic, Alaskan/Native American, Asian/Pacific Islander

($P < .001$, not shown) and higher FFM ($P < .001$, not shown) than white or "other" males.

Tables 3 and 4 present descriptive characteristics of males and females in the following three groups: small (subjects with M/SA smaller than −2 SD of the mean), large (subjects with M/SA larger than +2 SD of the mean), and average (subjects with M/SA between −2 SD and +2 SD). In nearly every instance, the values for all characteristics of males and females (Tables 3 and 4) predictably increased from small to average to large. However, large individuals were not significantly older than small or average individuals. It is also noteworthy that small males and females tended to have a higher VO_2max, expressed in ml · kg^{-1} · min^{-1}, than large and average males and females, in spite of a lower VO_2max expressed in liters · min^{-1}. Small males and females also completed the 2 mile run in less time than average and large.

DISCUSSION

Future research is required to clarify the relationships between M/SA and hyperthermia, heat tolerance, environmental factors, and anthropological factors. Most previous M/SA studies (Table 5) involved small sample sizes, young adults, and subjects of unspecified ethnic origin. It is clear that few researchers have considered the effects of age, gender, and ethnic group on M/SA or have utilized normative data in their design. In fact, several studies (Table 5) utilized groups of subjects who had very similar M/SA values (i.e., 33.4 vs. 35.5, 39.5 vs. 40.7, 35.7 vs. 38.7, 35.8 vs. 38.5 kg · m^{-2}). In addition, the studies summarized in Table 5 rarely focused on males and females who had M/SA values outside our 95% confidence limits. Out of the 32 mean M/SA values presented in Table 5, only one female and two male groups were less than −2 SD and only

TABLE 3. Comparison of male descriptive characteristics of three M/SA subsamples: small (n = 19), average (n = 1112), large (n = 34)[1]

Characteristic	Small		Average		Large	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	28.9	9.0	30.4	9.0	31.7	7.5
H (cm)	170.1	6.0	175.1	6.9	179.4	6.9
M (kg)	53.6	3.9	76.3	9.8	106.8	8.8
SA (m^2)	1.6	0.1	1.9	0.1	2.3	0.1
M/SA ($kg \cdot m^{-2}$)	33.2	0.8	39.7	0.2	47.4	1.4
%BF (%)	16.2	5.5	20.1	6.5	30.2	4.7
FFM (kg)	44.9	4.7	60.7	6.6	74.5	8.4
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.049	5.595	47.912	6.018	38.360	2.548
VO_2max ($liter \cdot min^{-1}$)	2.688	0.472	3.570	0.472	4.081	0.429
Two-mile run (min)	14.53	2.11	14.55	2.04	17.08	1.50

[1]Small, subjects with M/SA smaller than −2 SD of the mean; average, subjects with M/SA within ± 2 SD of the mean; large, subjects with M/SA larger than +2 SD of the mean.

TABLE 4. Comparison of female descriptive characteristics of three M/SA subsamples: small (n = 8), average (n = 286), large (n = 9)[1]

Characteristic	Small		Average		Large	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	25.0	7.0	24.0	5.0	28.0	3.0
H (cm)	159.9	2.6	162.4	6.3	165.0	10.8
M (kg)	45.0	1.5	59.6	6.9	78.9	7.9
SA (m^2)	1.4	0.3	1.6	0.1	1.9	0.2
M/SA ($kg \cdot m^{-2}$)	31.4	0.6	36.4	2.0	42.3	0.6
%BF (%)	21.5	7.5	27.3	5.3	33.3	7.5
FFM (kg)	35.4	4.7	43.7	6.7	53.7	8.4
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	41.000	5.329	39.420	4.345	34.125	3.563
VO_2max ($liters \cdot min^{-1}$)	1.858	0.296	2.330	0.300	2.725	0.525
Two-mile run (min)	18.14	2.04	18.43	2.20	19.46	2.17

[1]Small, subjects with M/SA smaller than −2 SD of the mean; average, subjects with M/SA within ± 2 SD of the mean; large, subjects with M/SA larger then +2 SD of the mean.

one female and one male group were greater than +2 SD from the mean (Table 1). Only seven (one female, six male) of 32 groups reported M/SA that were above the gender-appropriate mean of our sample (Fig. 1 and 2). This means that the subjects tested in most previous studies were not those at greatest theoretical risk of heat injury and that future studies should focus on males and females who lie outside the 95% confidence limits defined in the current investigation. Many studies have emphasized the increased risk of hyperthermia and heat illness in humans who have extremely low or extremely high M/SA indices and explain the purpose of Tables 3 and 4. The subsamples large and small in Tables 3 and 4 represent groups of humans who, theoretically, are at increased risk of incurring heat illness (see below). Comparison of the characteristics listed in Tables 3 and 4, therefore, provides experimental paradigms to test intraindividual differences in heat tolerance.

Age, gender, and ethnic group effects on M/SA

Intuitively, one might expect that M/SA would increase as age increases, but all males and females in Table 2 had similar M/SA values regardless of their age category. The effect of ethnic group was also minimal. Males and females in these age categories (Table 2) had similar M/SA indices. Compared with males of other nationalities, the current database indicated the following: 1) African Bantu and Pygmoid males (Austin and Ghesquiere, 1976) and 69 other African samples (Hiernaux et al., 1975) had M/SA indices below the mean of U.S. males (Table 1); 2) 60 Asian males (Benoist, 1975) fell approximately −1 SD from the mean of U.S. males; and 3) East European males (Benoist,

TABLE 5. Summary of previous physiological investigations which evaluated M/SA as an index of heat tolerance

Study	n Male	n Female	age (years) (Mean ± SD)	Ethnic group	M/SA ($kg \cdot m^{-2}$) (Mean ± SD)	Notes
Armstrong et al. (1987a)	14		28.4 ± 7.1	White	40.4 ± 3.6	
Austin and Ghesquire (1976)	10		—[1]	Black	35.5 ± —	African Bantu
	10		—	Black	33.4 ± —	African pygmoid
Avellini et al. (1980)	4		24.0 ± 4.2	—	38.5 ± —	Matched for VO_2max with females
		4	23.5 ± 1.9	—	35.8 ± —	Matched for VO_2max with males
Bar-or et al. (1969)		5	19.0 ± 1.2	—	45.9 ± 2.8	Obese
		4	21.2 ± 1.0	—	34.0 ± 0.8	Lean
Epstein et al. (1983)	5		23.5 ± 8.3	—	40.5 ± —	Heat stroke, heat intolerant
	9		20.5 ± 6.9	—	36.8 ± —	Heat stroke, normal tolerance
	9		19.1 ± 3.9	—	36.7 ± —	Healthy controls
Fein et al. (1975)		6	22.3 ± 2.5	—	36.5 ± 1.7	Students
		6	21.1 ± 3.2	—	36.4 ± 2.8	Students
Haymes et al. (1974)		5	10.2 ± 0.9	—	28.4 ± —	Lean, prepubertal
		7	10.1 ± 0.8	—	32.6 ± —	Obese, prepubertal
Miller and Blyth (1958)	14		23.8 ± —	—	38.9 ± —	Normal students
	14		20.5 ± —	—	50.1 ± —	Obese students
Piwonka et al. (1963)	7		22.6 ± 1.1	—	38.7 ± 3.0	Untrained
	5		21.2 ± 4.1	—	35.7 ± 0.8	Collegiate runners
Robinson (1942)	2		22-24[2]	—	35-44[2]	
Shapiro et al. (1980)		9	22.0 ± 3.0	—	35.6 ± —	Soldiers
	10		21.1 ± 1.9	—	39.2 ± —	Soldiers
Shvartz et al. (1973)	25		23.0 ± 3.5	White	38.6 ± —	
	8		22.0 ± 3.4	White	39.2 ± —	
Shvartz et al. (1977)	7		19.7 ± 1.3	—	37.2 ± —	Trained
	7		21.3 ± 1.5	—	38.2 ± —	Untrained
	7		19.0 ± 0.6	—	37.6 ± —	Unfit
	5		20.4 ± 2.7	—	37.7 ± —	Control subjects
Wailgum and Paolone (1984)	4		22.0 ± 0.8	—	45.5 ± —	Football linemen
	4		22.0 ± 2.6	—	41.7 ± —	Football backs
Wagner et al. (1972)	10		20-29[2]	—	39.5 ± —	Young men
	7		46-67[2]	—	40.7 ± —	Older men
	5		11-14[2]	—	30.7 ± —	Prepubertal
	5		15-16[2]	—	34.4 ± —	Postpubertal

[1]Information not available.
[2]Range.

1975) averaged virtually the same M/SA as U.S. males in the present investigation. Differences in heredity, nutrition, and activity, which affect %BF and FFM, probably explain these international M/SA differences.

The effect of gender on M/SA index was significant (Table 1), however. All female characteristics were smaller ($P < .001$) than those of males, except %BF and 2 mile run time, which were significantly larger ($P < .001$). The smaller M/SA index of females previously has been reported as a beneficial factor in hot, humid environments, evidenced by lower heart rate (HR) and rectal temperature (T_{re}) during exercise than males (Avellini et al., 1980; Paolone et al., 1978; Shapiro et al., 1980). However, when matched for M/SA and VO_2max (Avellini et al., 1980; Paolone et al., 1978; Shapiro et al., 1980), there were no significant differences in HR or T_{re} between the sexes. The fact that the mean M/SA index of average females differed from average males (Tables 3 and 4) by a minor amount (9.2%) suggests that M/SA may not influence heat tolerance significantly in these two subsamples.

Significance of stature

The significance of extremely small stature has been reported in previous studies (Austin and Ghesquiere, 1976; Strydom, 1980; Wagner et al., 1972). Austin and Ghesquiere (1976) examined the impact of extremely small stature (33.4 $kg \cdot m^{-2}$) on heat tolerance in African Pygmoids. They reported that HR and T_{re} were significantly higher in Pygmoids than in African Bantu males (35.5 kg $\cdot$ m^{-2}) and concluded that this was due to their extremely small stature rather than to differences in heat acclimatization or exercise capacity. Wagner et al. (1972) also focused on small body dimensions by evaluating prepubertal boys (30.7 kg $\cdot$ m^{-2}). The authors concluded that these boys were unable to regulate body temperature as well as postpubertal boys or men, because of their lower evaporative cooling capacity (e.g., smaller M/SA and lower sweat rate). Small males (Table 3) had a VO_2max of 2.688 liters $\cdot$ min^{-1}. This value is similar to the data published by Strydom (1980), which reported the mean VO_2max of 19 heat-intolerant males as 2.42 liter $\cdot$ min^{-1}. Furthermore, Strydom described the impact of low body weight on the heat tolerance of miners. Unacclimatized men with body mass of less than 50 kg (n = 23) were at greater risk of developing heat stroke than unacclimatized men of normal body mass. This 50 kg body mass was similar to that of small males in the current investigation (53.6 kg, Table 3). Thus the heat tolerance of our small subsample was theoretically less than average because of their extremely small stature.

The significance of extremely large stature has been supported by a variety of previous studies (Armstrong et al., 1988; Bar-Or et al., 1969; Miller and Blyth, 1958; Schickele, 1947; Shvartz et al., 1973). Wailgum and Paolone (1984) investigated football linemen who had large M/SA indices (45.5 kg $\cdot$ m^{-2}). These males were found to be at greater risk of hyperthermia than football backs (41.7 kg $\cdot$ m^{-2}), particularly while wearing uniforms in humid environments. Miller and Blyth (1958) tested the heat tolerance of 14 obese males (50.1 kg $\cdot$ m^{-2}), whereas Bar-Or et al. (1969) tested five obese females (45.9 kg $\cdot$ m^{-2}). Both research teams concluded that obese subjects exhibited inferior performance because of slower dissipation of stored heat, resulting from their high M/SA index. Schickele (1947) reported that heat stroke was more likely to lead to death in patients with large M/SA indices. Also, a recent case report (Armstrong et al., 1988) monitored a 32-year-old male (180 cm height, 110.47 kg body mass) who exhibited heat intolerance (days 5–8) and heat exhaustion (day 8) during an 8 day heat acclimation study. The M/SA index of this subject was extremely large (48.0 kg $\cdot$ m^{-2}) compared with 13 other males (mean 40.4 kg $\cdot$ m^{-2}) who completed the heat acclimation regimen without difficulties. Other studies have observed that low cardiovascular physical fitness, low exercise efficiency, high metabolic heat production, and low specific heat of adipose tissue are critical factors in the onset of hyperthermia in obese individuals (Bar-Or et al., 1969; Shvartz et al., 1973; Wailgum and Paolone, 1984). Large males in the current investigation had a mean %BF of 30.2%, compared to 20.1% and 16.2% for average and small, respectively (Table 3). This large %BF in large probably increased the tissue weight that could not utilize oxygen for muscular contraction, reduced exercise efficiency, and had a negative motivational effect on the amount of habitual participation in aerobic training (Vogel et al., 1986). Thus the heat tolerance of our large subsample was theoretically less than average (Tables 3 and 4) because of their extremely large stature.

In conclusion, the salient applications of the current investigation are as follows. First, normative M/SA data have been presented by which previous and future studies may be interpreted. These normative data are valuable because some previous studies have attributed intergroup heat tolerance differences to M/SA differences when between-group M/SA differences were small (Austin and Ghesquiere, 1976; Avellini et al., 1980; Epstein et al., 1983; Haymes, 1984; Piwonka et al., 1963) and did not include subjects who were theoretically likely to be heat intolerant (e.g., M/SA values outside the 95% confidence limits of subjects in the current investigation) (Bar-Or et al., 1969; Epstein et al., 1983; Shvartz et al., 1973; Wailgum and Paolone, 1984). These normative data also may be utilized to compare M/SA values of U.S. citizens with those of other ethnic groups. Second, the males and females who have the greatest theoretical risk of heat intolerance (Armstrong et al., 1988; Austin and Ghesquiere, 1976; Bar-Or et al., 1969; Miller and Blyth, 1958; Schickele, 1947; Shvartz et al., 1973; Strydom, 1980; Wagner et al., 1972; Wailgum and Paolone, 1984) have been described. Those humans whose M/SA approximates the small or large subsamples (Tables 3 and 4) may now be identified in groups of athletes, laborers, or soldiers. If future research verifies that small and large subsamples have reduced heat tolerance, these males and females may be eliminated objectively, or monitored closely, when performing tasks that involve strenuous exercise and either hot-humid environments or impermeable clothing.

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